



# **Dependence of contamination rates on key parameters in EUV optics**

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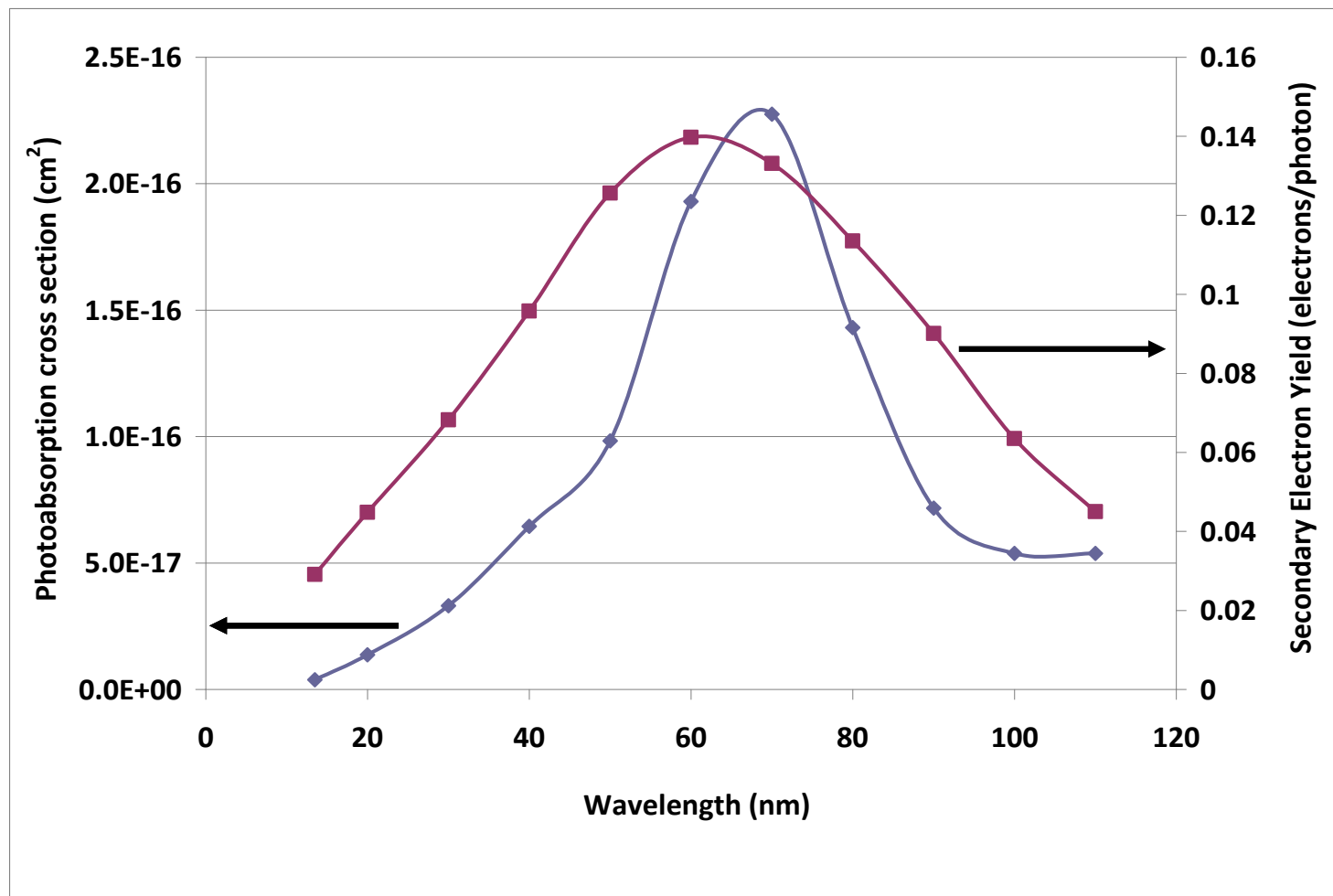
SEMATECH, 257 Fuller Road, Suite 2200, Albany, New York, 12203. USA



- Optics contamination remains one of the challenges in EUV Lithography
- We report on the contamination rate dependence on the following parameters:
  - Illumination wavelength
  - Capping layer species
  - Illumination angle
  - Hydrocarbon species
  - Mirror temperature



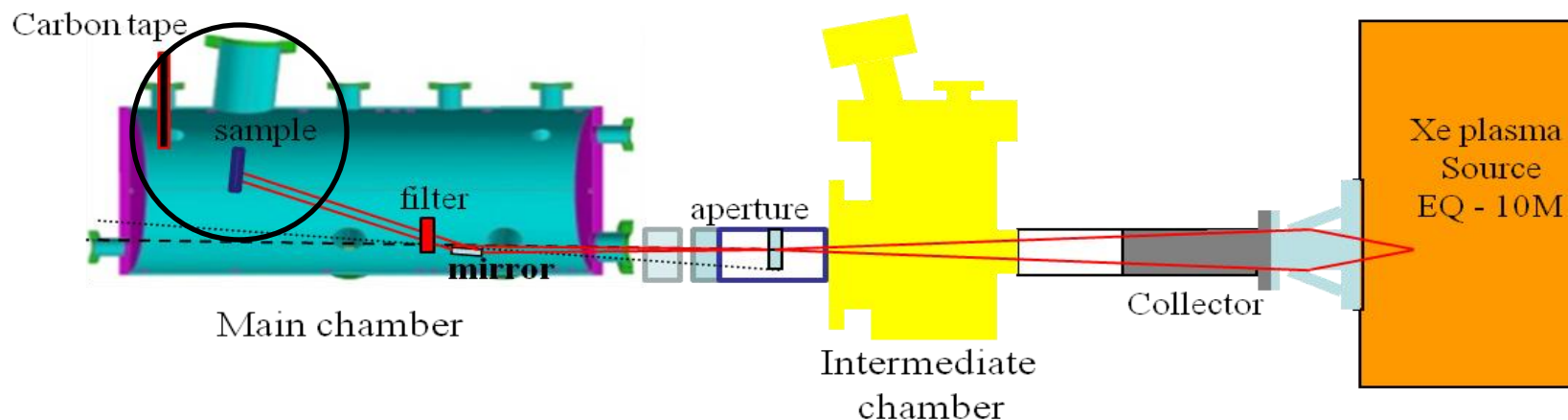
## CONCERN OF OOB RADIATION IN EUV TOOLS



Reference: V. Jindal, R. Garg, G. Denbeaux, and A. Wuest, *Proc. SPIE 7271*, 72713Q



## SETUP FOR LOW INTENSITY EXPERIMENTS



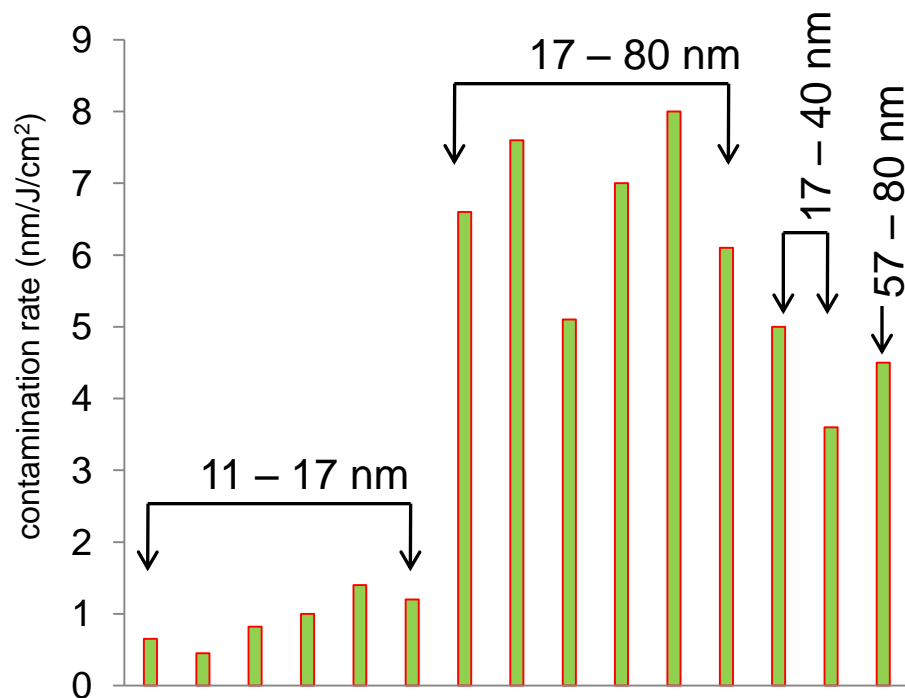
Filters	Wavelength range (nm)
Zr	11–17
Al	17–80
Al + Xe gas	17–40
Al + Ne gas	57–80

### Measured Intensities of Light:

- EUV radiation: 1 mW/cm<sup>2</sup>
- OOB radiation: 0.2 mW/cm<sup>2</sup>

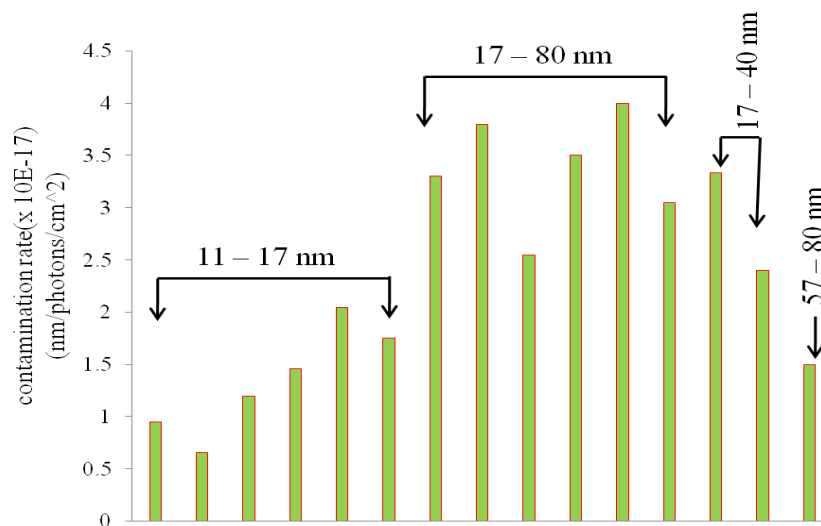


## CONTAMINATION DEPENDENCE ON WAVELENGTH



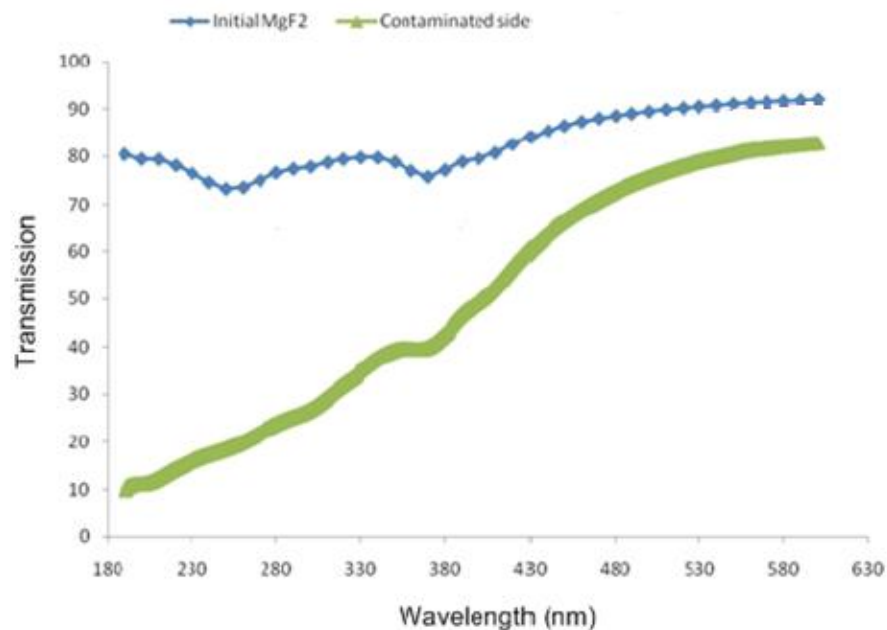
CONTAMINATION RATE PER  
DOSE FOR EUV AND OOB  
WAVELENGTH

CONTAMINATION RATE PER  
PHOTON FOR EUV AND OOB  
WAVELENGTH

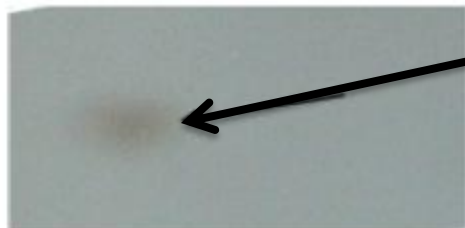




## EXPOSURES WITH DEUTERIUM ARC LAMP



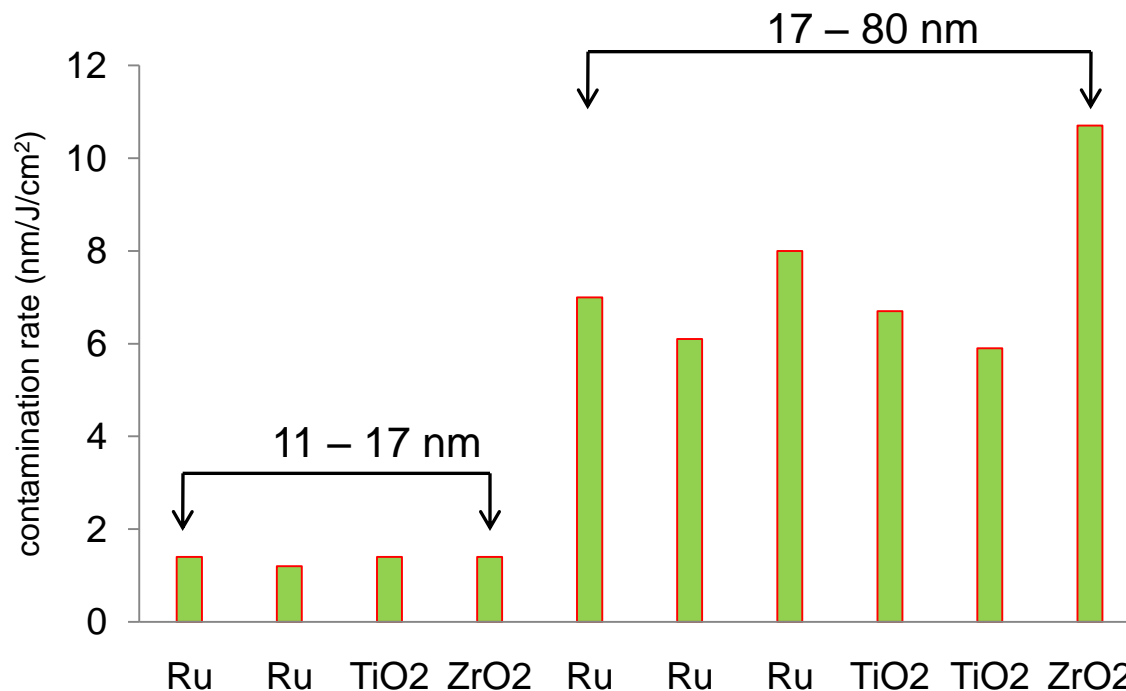
- Deuterium arc lamp emits 190 nm and higher wavelengths ( $< 7$  eV)
- Arc lamp illuminates witness plate in vacuum through MgF<sub>2</sub> window
- Contamination on both the vacuum side of the window and on the witness plate indicated even 190 nm and longer wavelengths is still a contamination concern



PHOTONS WITH ENERGY BELOW 7 eV CAN CAUSE CONTAMINATION



## CONTAMINATION DEPENDENCE ON CAPPING LAYERS

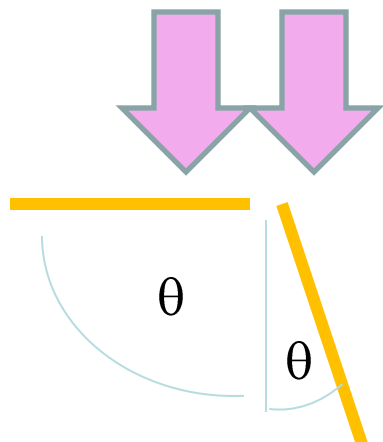


- **Contaminant species**: Heated carbon tape with an absolute pressure of low 10<sup>-4</sup> Torr to mid 10<sup>-5</sup> Torr during exposure
- **EUV light intensity**: 1 mW/cm<sup>2</sup>
- **OOB light intensity**: 0.2 mW/cm<sup>2</sup>

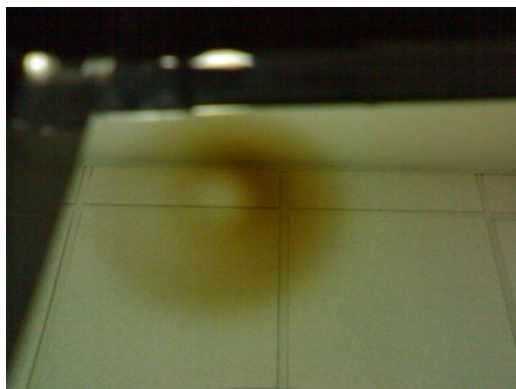
Results don't show measurable difference in contamination rate for different capping layers



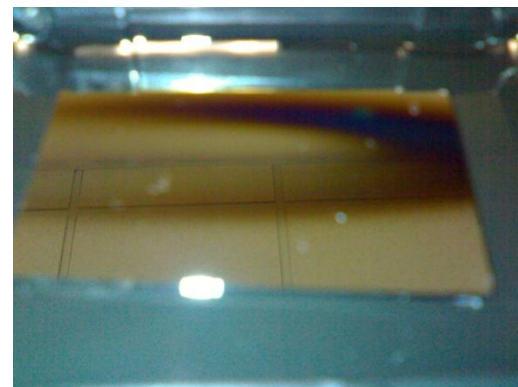
## CONTAMINATION DEPENDENCE ON ILLUMINATION ANGLE



Side-by-side exposures at two angles measured:  
16 degrees had 1.5 times more contamination than 90 degrees  
35 degrees had 1.2 times more contamination than 72 degrees



Normal Incidence

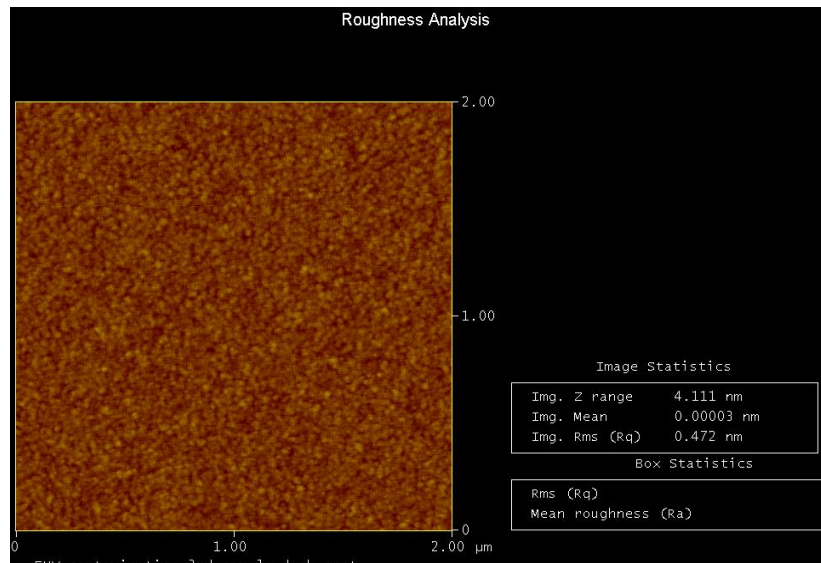


10 degrees from  
glancing angle

**Shallower angle illumination causes more contamination  
rate even though the dose/area is lower**

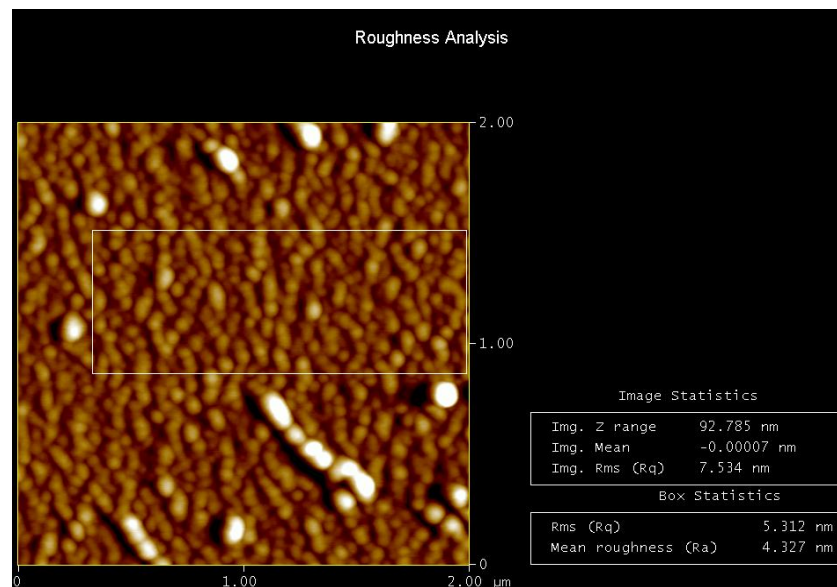


## ROUGHNESS ANALYSIS



Sample: Normal Incidence Exposure  
Roughness of contamination layer: 0.5 nm RMS  
Roughness of mirror surface below contamination: 0.3 nm RMS

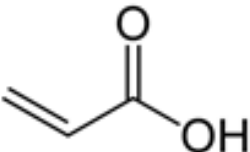
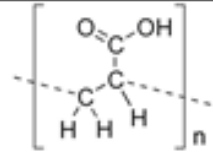
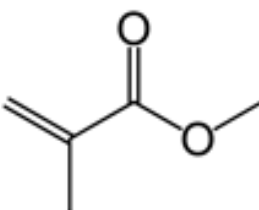
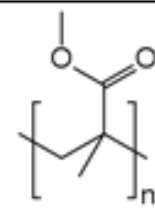
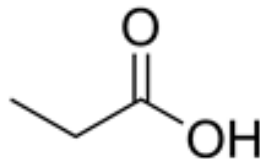
Sample: 10 Degrees from glancing angle  
Roughness of contamination layer: 5 nm in smoother region and 8 nm overall



**Shallower angles cause an increased roughness of the contamination layer**



## CONTAMINATION DEPENDENCE ON SPECIES

Species	Composition	Structure	Boiling Point	Polymer structure
Acrylic Acid	$C_3H_4O_2$		414 K	
Methyl Methacrylate	$C_5H_8O_2$		374 K	
Propionic Acid	$C_3H_6O_2$		414 K	N/A



## Comparison of contamination rate of Acrylic Acid and Propionic Acid exposures



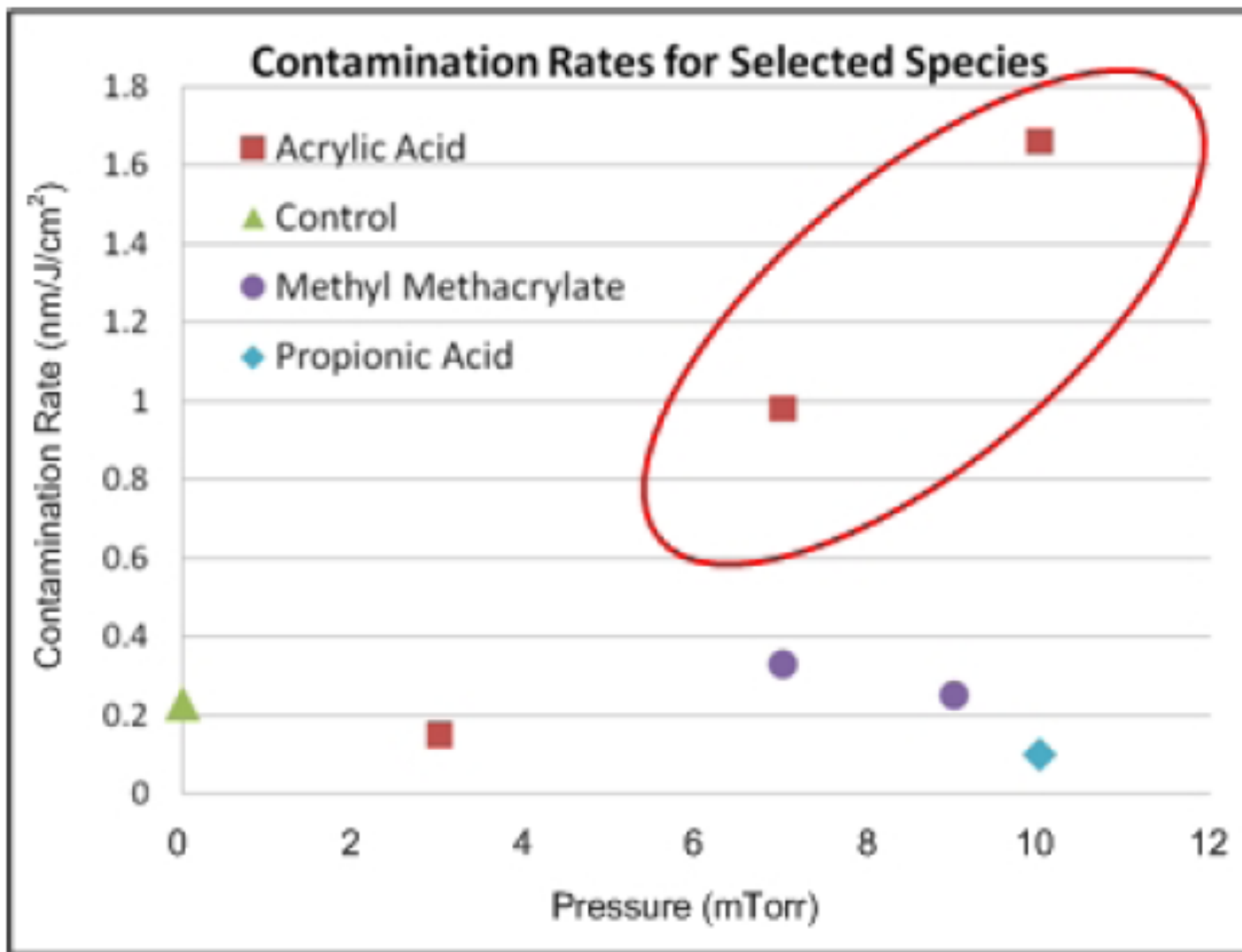
- XPS area map of the contamination from a 10 mT background pressure of Acrylic Acid
- Peak contamination thickness is 5 nm
- Contamination Rate of  $\sim 1.7$  nm/J/cm<sup>2</sup>

ACRYLIC ACID CONTAMINATION



- XPS area map of the contamination from a 10 mT background pressure of Propionic Acid
- Contamination thickness not measurably different than background

PROPIONIC ACID CONTAMINATION

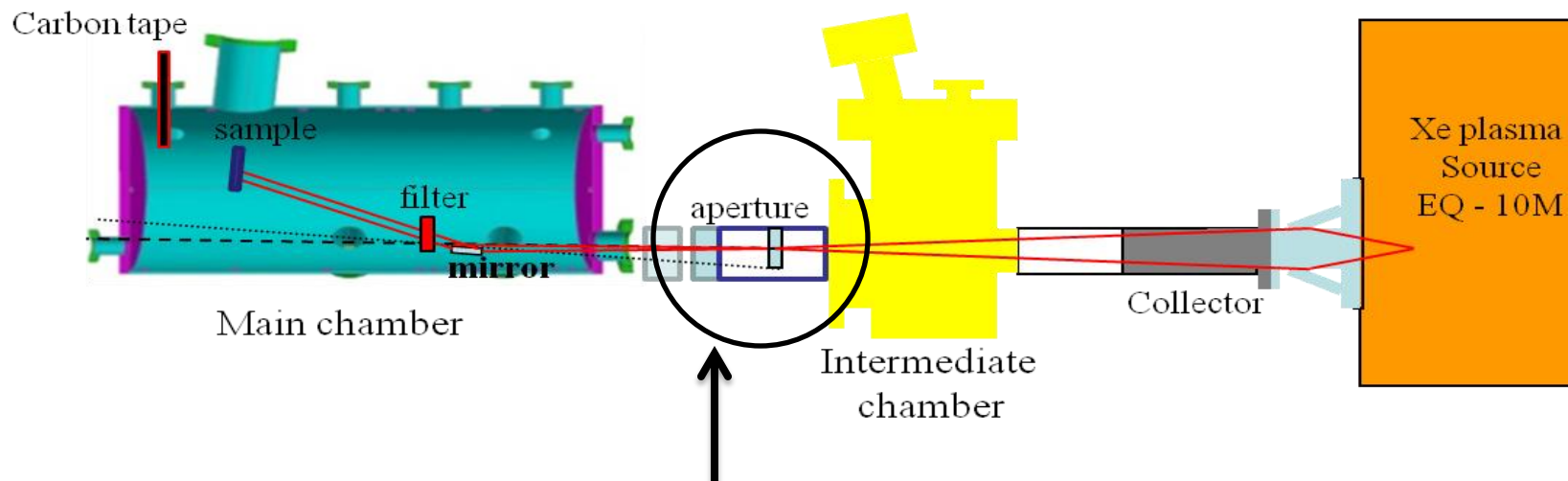


Acrylic acid which can polymerize is a faster contaminant than propionic acid

Methyl methacrylate can also polymerize but does not contaminate as fast as acrylic acid



## SETUP FOR HIGHER INTENSITY EXPERIMENTS



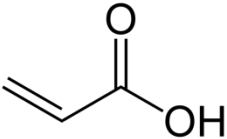
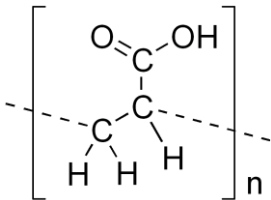
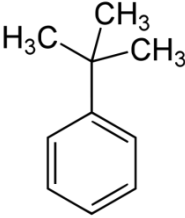
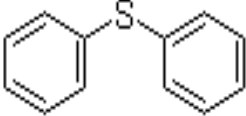
Exposures at this sample plane:

- Species Dependence
- Temperature Dependence

High Volume Manufacturing estimated to be  $650 \text{ mW/cm}^2$  on mask  
These exposures are  $100 \text{ mW/cm}^2$

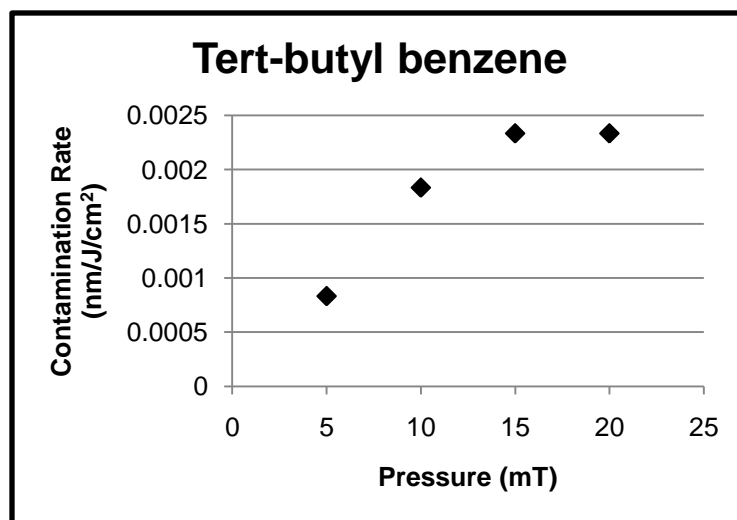
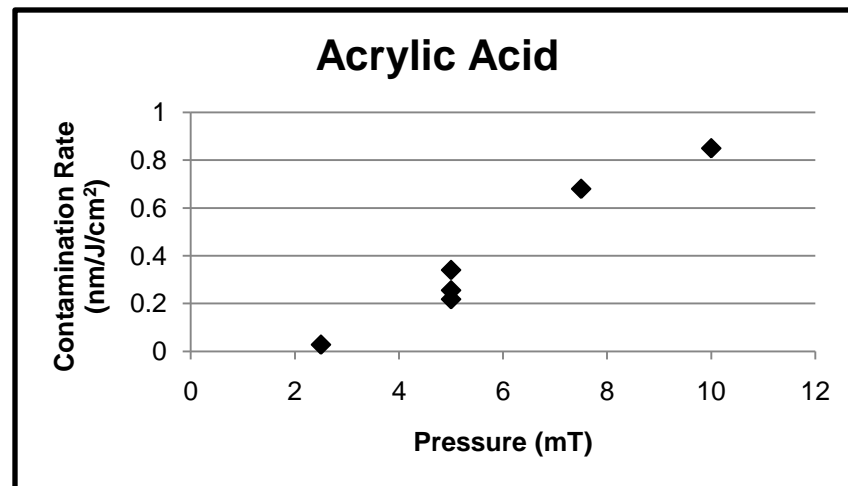
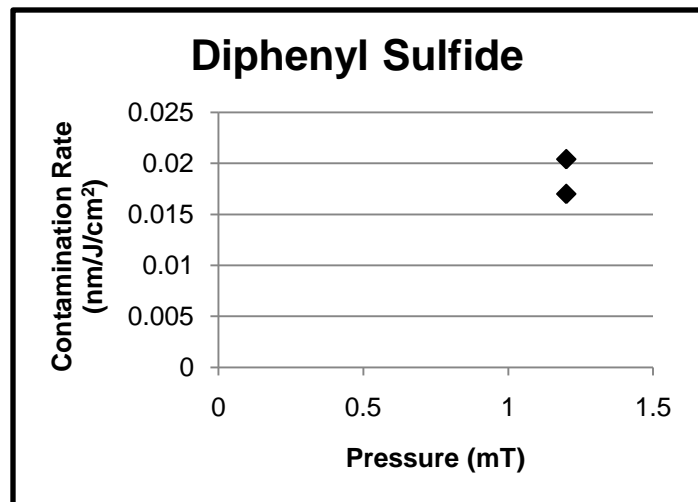


## LIST OF SPECIES FOR HIGH INTENSITY EXPERIMENTS

Species	Composition	Structure	Boiling Point	Polymer Structure
Acrylic Acid	$C_3H_4O_2$		414 K	
Tert-butylbenzene	$C_9H_{12}$		442 K	N/A
Diphenyl Sulfide	$C_{12}H_{10}S$		569 K	N/A



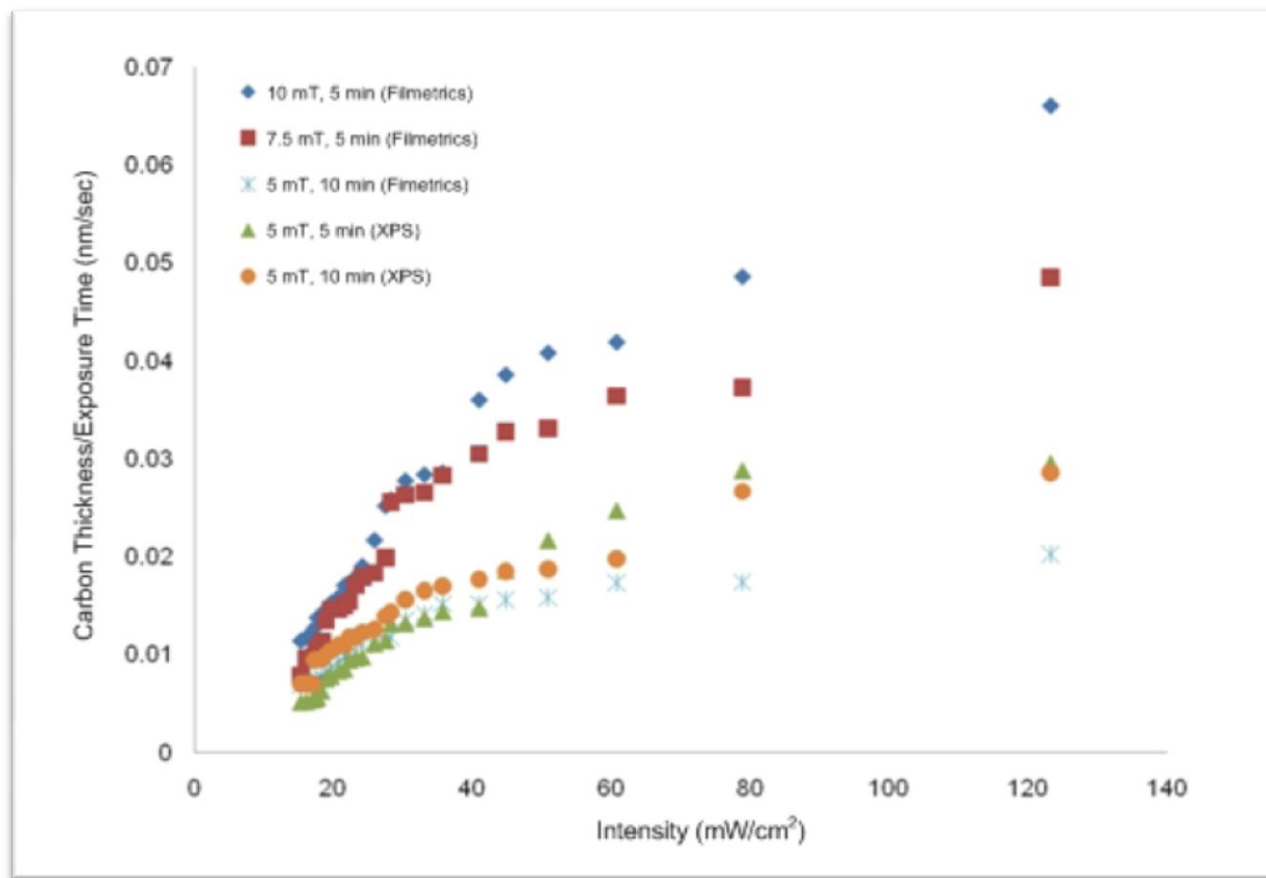
## CONTAMINATION DEPENDENCE ON SPECIES



Acrylic acid and diphenyl sulfide have similar rates of contamination  
Tert-butylbenzene is an order of magnitude lower



## CONTAMINATION RATE DEPENDENCE ON INTENSITY



- The 5- and 10- minute exposures at 5 mTorr have the same rate
- Higher pressure acrylic acid contaminates at a higher rate



## CONTAMINATION DEPENDENCE ON TEMPERATURE

Temperature (°C)	Maximum Carbon Thickness on Sample (nm)
10	60
10*	20*
22	8.5

- Reducing the temperature of the optic causes increased contamination

\* Sample may not have reached equilibrium with the cooling line in the duration of the experiment



# SUMMARY OF WORK

- Out-of-band radiation contamination rate is higher than EUV radiation
- Contamination on different capping layers gave approximately same contamination rate
- Contamination rate increases for shallower illumination angles
- The roughness of the contamination layer increases for shallower illumination angles
- There may be a link between species that self-polymerize and increased contamination rate

